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LATE CRETACEOUS AND TERTIARY FLORAS, VEGETATION, AND PALEOCLIMATES OF NEW ENGLAND

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ABSTRACT

Late Cretaceous and Tertiary plant fossils are found in relatively few places in New England, but the fossil record is sufficient to provide a general impression of changes in floras, vegetation types, and climates in the region during this time span. Late Cretaceous pollen and plant megafossils of Massachusetts and Rhode Island are poorly known with regard to their affinities with modern taxa, but the fossils show that the subhumid paratropical Normapolles province of the eastern United States extended at least as far north as New England. Paleocene and early Eocene pollen assemblages from Massachusetts are important because they suggest that the tropical rainforests of the Gulf and Atlantic Coastal Plains extended with considerable taxonomic uniformity at least as far north as New England. The Eocene flora is quite similar to the coeval flora of Europe, partly because of migration from Europe to North America at the beginning of Eocene time. The late Oligocene pollen and megafossil flora of Vermont and the middle Miocene pollen flora of Massachusetts probably represent Mixed Mesophytic forest. One or both of these floras included exotic elements such as *Glyptostrobus, Podocarpus, Sciadopitys, Alangium,* Engelhardieae, *Phellodendron,* and *Turpinia.* Two pollen assemblages of probable Pliocene age are known from Martha's Vineyard; they represent a cool temperate vegetation.

Key Words: Cretaceous, Tertiary, palynology, paleobotany, New England

INTRODUCTION

Late Cretaceous and Tertiary plant fossils occur in only a few places in New England (Figure 1, Table 1). The purpose of this paper is to evaluate the quality of fossil plant data available from New England and to combine plant megafossil and pollen data in order to arrive at a history of the Late Cretaceous and Tertiary floras, vegetation types, and climates in the region.

Late Cretaceous and Tertiary plant fossils in New England represent a total time span of about 93 to about 1.5 million years ago (Ma.), a total of slightly more than 90 million years (Figure 2). However, the fossil plant record is not a continuous one by any means; it is very spotty, and a much more fragmentary record than Figure 2 suggests. The problem is that beneath the glacial deposits that cover much of New England, most rocks in this region are older than Cretaceous.

Most Late Cretaceous and early Tertiary palynological studies

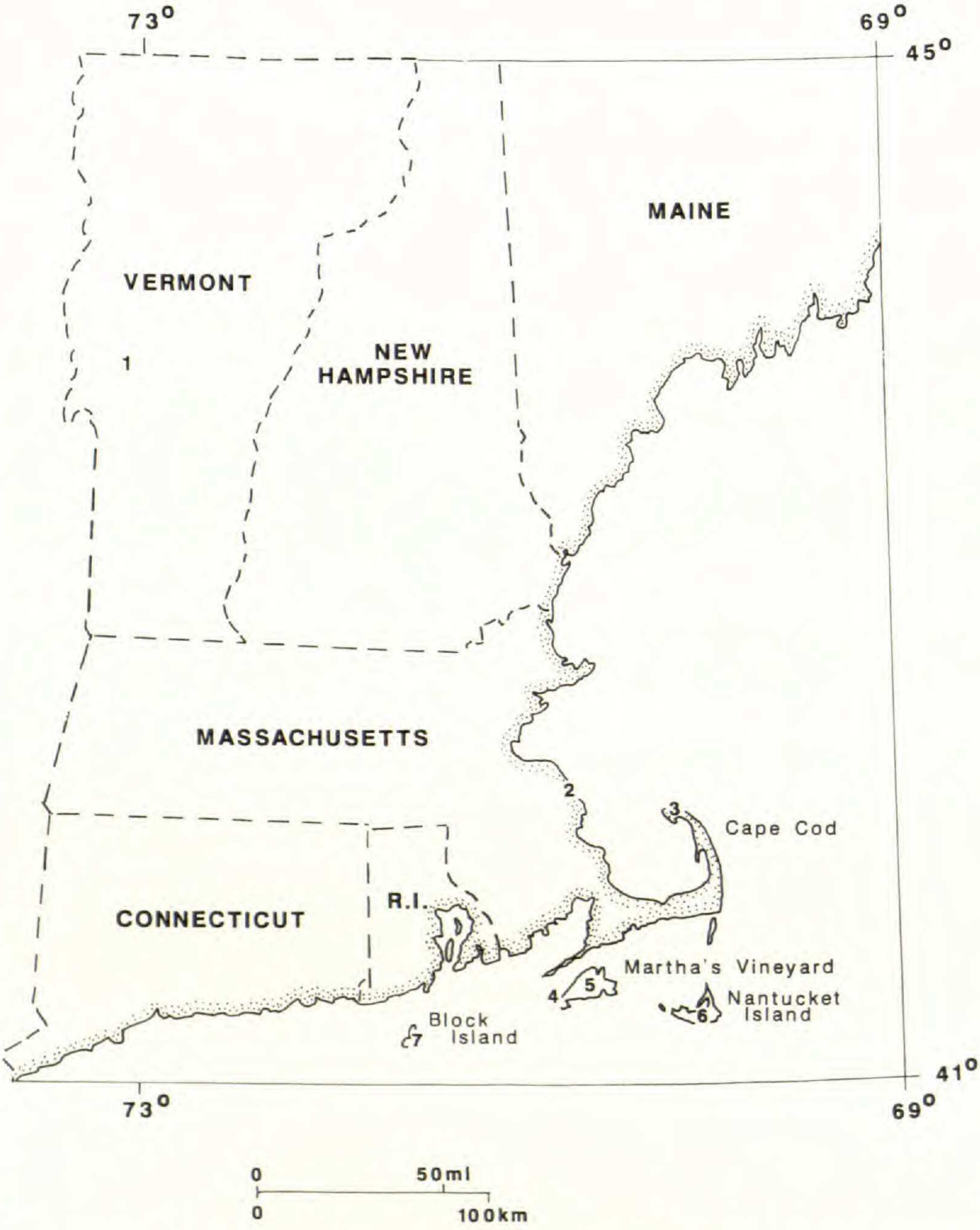

Figure 1. Map showing localities in New England from which Late Cretaceous and Tertiary plant fossils have been studied. Ages of deposits at each locality are given in Table 1.

in New England were concerned primarily with biostratigraphic problems. These studies generally disregarded spores and gymnosperm pollen, which typically have simple morphologies compared with angiosperm pollen; thus, spore and gymnosperm pollen species commonly have long stratigraphic ranges. Furthermore, Late Cretaceous megafloras in the region seem to include only

Table 1. List of Late Cretaceous and Tertiary plant localities in New England.

Locality, Figure 1	State	Locality Description	Age	Reference
1	VT	Village of Forestdale, northeast of Brandon	Probably late Oligocene	See references in Table 2
2	MA	Scituate Third Cliff, Plymouth County	Miocene[1]	Frederiksen (1984a)
2	MA	North and south gravel pits, east of Marshfield Center, Plymouth County	Miocene[1]	Frederiksen (1984a)
2	MA	U.S. Geological Survey Marshfield Cranberry Bog no. 1 corehole, west of Marshfield, Plymouth County	Miocene[1]	Frederiksen (1984a)
3	MA	3 wells near Holden's Pond, Cape Cod	Miocene?[1]	Zeigler et al. (1960), Groot and Groot (1964)
4	MA	Gay Head Cliffs, Martha's Vineyard	Miocene and Pliocene	Frederiksen (1984a)
4	MA	Gay Head Cliffs, Martha's Vineyard	Cenomanian to Campanian	Hollick (1906), Miller and Robison (1975), Tiffney (1977c)
4	MA	Zacks Cliffs, Martha's Vineyard	Miocene	Frederiksen (1984a)
5	MA	U.S. Geological Survey well ENW-50, east-central Martha's Vineyard	Cenomanian	Hall et al. (1980)
6	MA	U.S. Geological Survey borehole 6001, central Nantucket Island	Cenomanian; Coniacian to Campanian	Folger et al. (1978)
7	RI	Beach cliff outcrops in southeastern and northeastern Block Island	Turonian to Coniacian	Sirkin (1974)

[1] Contains redeposited Late Cretaceous, Paleocene, and Eocene pollen.

sparse pteridophyte and gymnosperm fossils. Therefore, in this paper the emphasis is on angiosperm fossils, although gymnosperm pollen is abundant and important in the late Tertiary.

LATE CRETACEOUS OF MASSACHUSETTS AND RHODE ISLAND

Hollick (1906), Miller and Robison (1975), and Tiffney (1977c) described the rich plant megafossil flora from Gay Head, Martha's Vineyard. The fossils consist mainly of leaves and include 4 species of ferns, 4 of gymnosperms, 2 of monocots, and about 80 of dicots. The specimens came from rocks assigned to the Raritan and Magothy Formations of New Jersey, which are Cenomanian to earliest Coniacian, and Coniacian to early Campanian in age, respectively (ages of Cretaceous formations are from Christopher, 1978, 1979; *see* Figure 2).

In addition to megafossils, Cretaceous pollen has also been found. In a borehole on Nantucket Island (Folger et al., 1978) the assemblages were Cenomanian, late Coniacian to Santonian, and Campanian in age; in a well on Martha's Vineyard (Hall et al., 1980), the pollen assemblage was Cenomanian; and in an outcrop on Block Island, Rhode Island (Sirkin, 1974), the assemblage was Turonian to Coniacian in age (Figure 2). Only a few stratigraphically important taxa were listed from each of these pollen assemblages, but apparently the entire assemblages are similar to those from New Jersey, which are fairly well known (Christopher, 1979, and references therein).

Hollick (1906) assigned many of his megafossils to modern genera, but it has since been found that these identifications with extant taxa are very unreliable even at the level of family or order (Wolfe and Upchurch, 1987). In addition, most Cretaceous plant megafossils cannot be linked to particular taxa of pollen and spores, which are also largely of uncertain affinity even at order level. Therefore, it is impossible to speak very meaningfully of the Late Cretaceous floras from North America in terms of modern taxa.

Some evidence exists as to the nature of the Late Cretaceous vegetation and climate on the East Coast, but the climatic evidence is equivocal. Parrish and Curtis (1982), Parrish et al. (1982), and Parrish (1987) presented a paleoclimatic model based on continental topography and positions of the continents. According

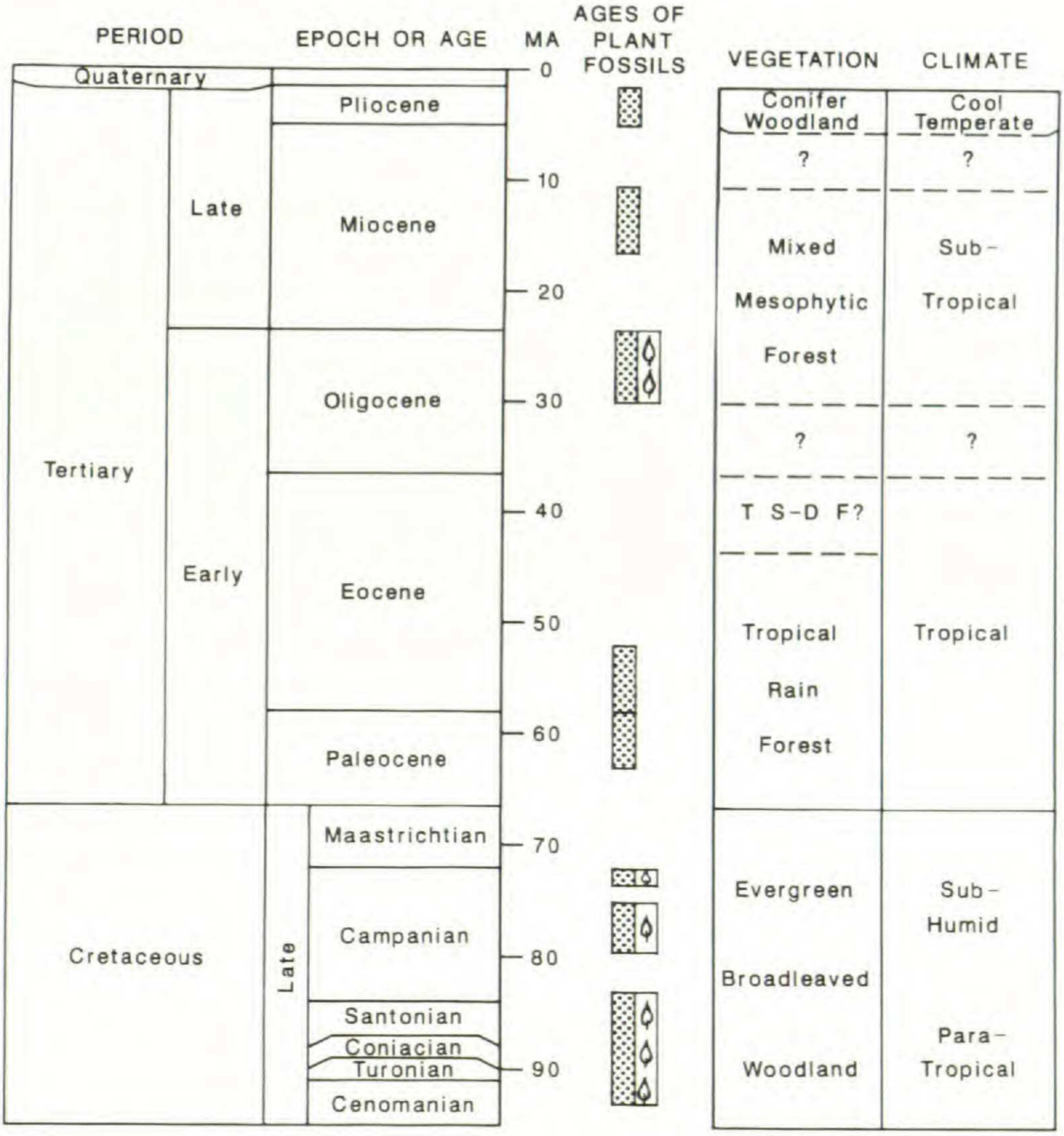

Figure 2. Ages of rocks in New England from which Late Cretaceous and Tertiary plant fossils have been studied (geochronologic ages from Berggren et al., 1985, and Hallam et al., 1985) and inferred vegetation types and climates of this time span in New England (Frederiksen, 1984a; Wolfe, 1985; Upchurch and Wolfe, 1987; Wolfe and Upchurch, 1987). Ma = megaannums = millions of years ago. Boxes only indicate maximum time spans that could be represented by known plant fossils. Dot pattern = pollen and spores; leaf pattern = megafossils. TS-DF = Tropical Semi-Deciduous Forest.

to this model, in the Late Cretaceous, the East Coast should have been humid all year because of the year-round presence of a subtropical high-pressure cell in the North Atlantic centered between 30° and 45°N lat. In contrast, studies of leaves, wood, and seeds (Wolfe and Upchurch, 1987; Upchurch and Wolfe, 1987) suggest that the Late Cretaceous of the East Coast was subhumid;

the vegetation apparently consisted of "open-canopy, broad-leaved evergreen woodland that existed under low to moderate amounts of rainfall evenly distributed through the year" (Wolfe and Upchurch, 1987, p. 33). At least both the Parrish and Wolfe-Upchurch models agree that rainfall was relatively constant throughout the year. Leaf characteristics also suggest that the climate was mainly paratropical, that is, the mean annual temperature was 20° to 25°C (Upchurch and Wolfe, 1987).

Judging by leaf characteristics, most taxa in the vegetation were evergreen rather than deciduous (Wolfe, 1987). A significant proportion of the flora was probably wind-pollinated: throughout the eastern United States, some of the most common pollen grains in Late Cretaceous strata belong to the Normapolles group and (in latest Cretaceous time) to the triporate group. The triporates were probably produced by Betulaceae, Juglandaceae, Myricaceae, and Ulmaceae (Thomson and Pflug, 1953; Crepet, 1981). The Normapolles group is much more heterogeneous morphologically and probably also in its botanical affinities (Zaklinskaya, 1981; Batten, 1984). However, some pollen of the Normapolles group was produced by wind-pollinated flowers of the Juglandales-Myricales complex (Friis, 1983) and, from morphological features of the dispersed pollen, it has long been thought that many taxa of the Normapolles group were wind-pollinated (*see* Frederiksen, 1985). The paradox thus arises that the presence of a distinct wind-pollinated element in the vegetation suggests a seasonally dry climate (Crepet, 1981; Batten, 1984), but leaf and wood characteristics indicate the lack of a pronounced dry season (Wolfe and Upchurch, 1987). Perhaps, as Crepet (1981) suggested, some degree of wind pollination was advantageous in the Cretaceous vegetation because not enough taxa of skilled pollinating insects had yet evolved. Alternatively, or concomitantly, the existence of open canopy vegetation and relatively low rainfall in the Late Cretaceous may have encouraged the development of wind pollination (Batten, 1984; Upchurch and Wolfe, 1987).

Phytogeographically, the Atlantic Coastal Plain was part of the Normapolles floristic province (Figure 3) that extended during Late Cretaceous and Paleocene time from the Midcontinental Seaway of North America to western Europe (Samoilovich, 1977; Zaklinskaya, 1977). For any particular time span in the Late Cretaceous, a considerable degree of similarity exists among pollen assemblages collected at sites from South Carolina to New

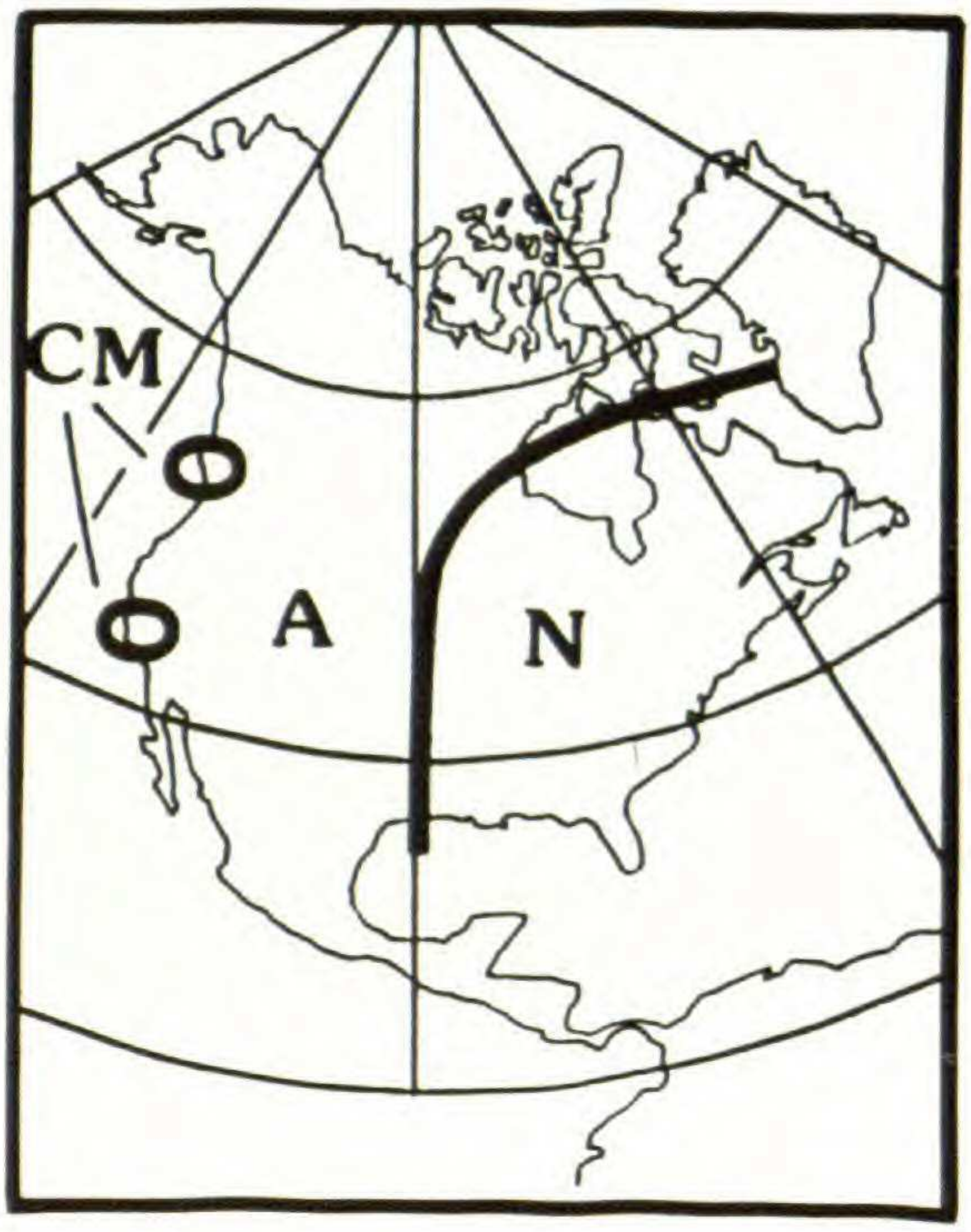

Figure 3. Map of latest Cretaceous floristic provinces in North America (from Frederiksen, 1987, Figure 1F; courtesy of *Palaios* and the Society of Economic Paleontologists and Mineralogists). A = *Aquilapollenites* province; CM = continental margin province; N = Normapolles province.

Jersey (Christopher, 1978). The pollen data from New England and sparse pollen data from offshore Canadian wells (Williams and Brideaux, 1975) indicate that the Late Cretaceous Normapolles province of North America extended, perhaps with little floristic change, at least as far north as southeastern Canada. The presence of rare *Aquilapollenites* pollen in Late Cretaceous assemblages from Massachusetts (Frederiksen, 1984a), New Jersey and Maryland (Evitt, 1973) may be a result of long-distance air transport of the pollen or may actually indicate a small but distinct floristic interchange with the *Aquilapollenites* province far to the west and north (Figure 3; Evitt, 1973).

PALEOCENE OF MASSACHUSETTS

Very little is known about the Paleocene flora of New England because the plants are represented only by rare redeposited pollen of Paleocene age in Miocene strata of Plymouth County and in probable Miocene strata of Cape Cod, Massachusetts (Groot and Groot, 1964; Frederiksen, 1984a). "Redeposited" means that in

Miocene time, Paleocene rocks containing Paleocene pollen were exposed at the surface; these rocks were eroded by streams and waves, and the sediments, with their Paleocene pollen, were transported a short distance, and then deposited again to form a Miocene sediment. A fascinating aspect of the Miocene rocks is that they actually contain redeposited pollen of Late Cretaceous, Paleocene, and Eocene ages, all in the same samples, accompanied by indigenous Miocene pollen (Frederiksen, 1984a).

Redeposited Paleocene pollen from New England and sparse indigenous Paleocene pollen and spores in offshore Canadian wells (Williams, 1974; Williams and Brideaux, 1975) are similar to taxa known to the south in the Atlantic Coastal Plain and in the Gulf Coast. The pollen and spores suggest that the Normapolles province (modified floristically from its Cretaceous predecessor but still definable because of its Normapolles pollen) continued to extend at least as far north as southeastern Canada in the Paleocene.

Climatically, the Paleocene of the East Coast is thought to have been warmer and moister than the Late Cretaceous, leading to the widespread development of multistratal tropical rainforest (Upchurch and Wolfe, 1987). The most notable trends during the evolution of Paleocene pollen floras in eastern North America were (1) a low initial pollen diversity followed by a distinct increase in diversity, (2) rapid evolution of juglandaceous pollen forms, (3) first appearances of important pollen morphotypes such as *Carya, Symplocos,* thick-walled *Alangium,* Restionaceae, and *Proxapertites* (an extinct relative of the tropical brackish-water palm *Nypa*), and (4) a gradual reduction in number of species of the Normapolles group.

EOCENE OF MASSACHUSETTS

Eocene floras of New England are known only from pollen redeposited into Miocene and possible Miocene strata in Massachusetts (Zeigler et al., 1960; Groot and Groot, 1964; Frederiksen, 1984a). From known ages of the pollen species elsewhere in eastern North America, it appears that this pollen in Massachusetts is entirely early Eocene in age. Therefore, no primary plant record exists for most of Eocene time in New England (Figure 2).

Based on morphologic features of fossil leaves from the Mississippi Embayment, western North America, and Greenland (that is, from localities far from New England), Wolfe (1985) suggested that the latest Paleocene to earliest Eocene vegetation of New England may have been tropical rainforest like the reconstructed vegetation of the same age in the Gulf Coast. Most Eocene pollen taxa had broad geographic ranges extending throughout the eastern United States, as shown by data in the many papers published on Eocene pollen from the upper Mississippi Embayment to the Gulf Coast, and north to Virginia (references in Frederiksen, 1979, 1980, 1988). The fairly rich Eocene pollen assemblage from Massachusetts and sparse Eocene pollen from Canadian offshore wells (Williams and Brideaux, 1975) indicate that the Eocene forests of the Gulf and Atlantic Coastal Plains extended with considerable or even large taxonomic uniformity as far north as southeastern Canada.

One of the most interesting features of the early Eocene flora of eastern North America is its considerable similarity to the coeval flora of western Europe. There is strong evidence for migration of both terrestrial vertebrates and plants across a northern land bridge between Europe and North America early in Eocene time (McKenna, 1975, 1983; Tiffney, 1985; Frederiksen, 1988). At least six plant taxa appear to have migrated from Europe to North America in early Eocene or possibly in very latest Paleocene time (Frederiksen, 1988), and these include the important genera *Platycarya* (Juglandaceae) and *Eucommia* (Eucommiaceae); this is the most distinct plant-migrational event known during early Tertiary time in North America. *Eucommia* was not found in the Eocene material in Massachusetts, but these assemblages did include four or five species or species groups within the *Platycarya* complex (*Platycarya* perplex of Wing and Hickey, 1984). Later in Eocene or early in Oligocene time, both *Eucommia* and *Platycarya* became extinct in North America and now are native only in eastern Asia.

OLIGOCENE OF VERMONT

The fossil flora of Brandon, Vermont, has been extensively studied with regard to pollen, fruits and seeds, and wood (references in Table 2). A diverse flora has been identified, including at least 39 modern genera and generic groups (three of them tentatively identified) (Tables 2, 3). The age of this deposit has

Table 2. Modern genera in the Oligocene Brandon deposit that do not now occur in New England or whose geographic ranges are mainly south of New England. References for generic identifications: Spackman (1949), Traverse (1955), Eyde and Barghoorn (1963), Eyde et al. (1969), Tiffney and Barghoorn (1976, 1979), Tiffney (1977b, 1979, 1980, 1981, 1985). Taxa marked * were identified on the basis of megafossils but not pollen.

Genus	Do Not Now Occur in U.S.; Mainly Found in Warmer Regions than Present New England	Occur in U.S. but Only South of New England	New England Is Near Northern End of Present Range
Alangium (Alangiaceae)	X		
*Caldesia** (Alismataceae)	X		
*Cleyera** (Theaceae)	X		
Cyrilla (Cyrillaceae)		X	
Engelhardieae (Juglandaceae)	X		
*Euodia** (Rutaceae)	X		
Glyptostrobus (Taxodiaceae)	X		
Gordonia (Theaceae)		X	
Ilex (Aquifoliaceae)			X
*Illicium** (Illiciaceae)		X	
Liquidambar (Hamamelidaceae)			X
Ludwigia (Onagraceae)			X
*Magnolia** (Magnoliaceae)			X
Manilkara-Mimusops group (Sapotaceae)		X	
*Microdiptera** (Lythraceae)	X		

Table 2. Continued.

Genus	Do Not Now Occur in U.S.; Mainly Found in Warmer Regions than Present New England	Occur in U.S. but Only South of New England	New England Is Near Northern End of Present Range
Nyssa (Nyssaceae)			X
*Persea** (Lauraceae)		X	
*Phellodendron** (Rutaceae)	X		
Planera (Ulmaceae)		X	
Pterocarya (Juglandaceae)	X		
Symplocos (Symplocaceae)		X	
*Turpinia** (*Staphyleaceae)*	X		
Vitis (Vitaceae)			X
*Zanthoxylum** (Rutaceae)			X

Table 3. Modern taxa recorded from the Oligocene pollen flora of Vermont (Traverse, 1955) and the Miocene pollen flora of Massachusetts (Frederiksen, 1984a).

	Miocene	Oligocene
TREES		
Gymnosperms		
Pinaceae		
Abies	?	
Larix	?	
Picea	X	
Pinus	X	X
Tsuga	X	
Podocarpaceae		
Podocarpus	X	
Taxodiaceae-Cupressaceae-Taxaceae	X	
Glyptostrobus		X
Sciadopitys	X	
Dicotyledons		
Alangiaceae		
Alangium		X
Aquifoliaceae		
Ilex	X	X
Betulaceae		
Alnus	X	
Betula	X	
Corylus	X	?
Clethraceae		
Clethra		?
Cornaceae	?	
Cyrillaceae		
Cyrilla-Cliftonia	X	X
Fagaceae		
Castanea	X	X
Fagus	X	X
Quercus	X	X
Hamamelidaceae		
Liquidambar	X	X
Juglandaceae		
Carya	X	X
Engelhardieae	X	X
Juglans	X	X
Pterocarya	X	X
Moraceae		
Morus	?	X
Nyssaceae		
Nyssa	X	X
Platanaceae		
Platanus	X	

Table 3. Continued.

	Miocene	Oligocene
Rhamnaceae		
Rhamnus		X
Rosaceae		?
Rutaceae		
Toddalieae		X
Salicaceae		
Salix	X	
Sapotaceae	X	X
Symplocaceae		
Symplocos	X	X
Theaceae		
Gordonia	X	X
Tiliaceae		
Tilia	X	X
Ulmaceae		
Planera		X
Ulmus-Zelkova	X	X
LOW SHRUBS, HERBS, VINES		
Anacardiaceae		
Rhus		X
Chenopodiaceae-Amaranthaceae	X	
Compositae, short-spined and long-spined	X	
Cyperaceae	?	
Elaeagnaceae	?	
Ephedraceae		
Ephedra	?	
Ericaceae	X	X
Gramineae	X	X
Malvaceae	X	
Myricaceae		
Comptonia	?	
Myrica	X	
Onagraceae		
Ludwigia	X	X
Santalaceae		
Nestronia		?
Umbelliferae	X	
Vitaceae		
Parthenocissus		X
Vitis		X
AQUATICS AND SEMIAQUATICS		
Haloragidaceae		
Myriophyllum	X	
Sparganiaceae-Typhaceae		
Sparganium-Typha	X	

not been precisely determined, but it represents a small slice probably of late Oligocene or possibly of earliest Miocene time (B. H. Tiffney, written comm., 1981); in this paper it will be considered late Oligocene in age.

Some of the most striking aspects of the Brandon swamp flora and vegetation are the scarcity of herbs and gymnosperms and the abundance of dicotyledonous trees and shrubs (Traverse, 1955; Tiffney, 1977a). Pollen thought to have been produced by herbs is generally not abundant in early Tertiary rocks of eastern North America, and some of the herb pollen genera identified in Paleocene and Eocene rocks seem to have become extinct in this region by the end of the Oligocene (e.g., *Pistillipollenites,* Gentianaceae; *Milfordia,* Restionaceae). Furthermore, during most of early Tertiary time, many herb niches were occupied by pteridophytes and not by angiosperms (Frederiksen, 1985). Many families of herbs had evolved in the Northern Hemisphere by the end of Oligocene time (Daghlian, 1981; Muller, 1981), but pollen of these families is rare in Oligocene rocks and is commonly sparse even in Miocene rocks of eastern North America (Traverse, 1955; Leopold, 1969; Rachele, 1976; Frederiksen, 1980, 1984a, 1984b, 1988; Owens et al., in press). In short, late Oligocene samples from eastern North America generally lack the typical Paleocene and Eocene herb pollen taxa, and they also lack the herb pollen types that are probably restricted to the late Tertiary and Quaternary in this region (Table 3).

COMPARISON OF EOCENE AND OLIGOCENE FLORAS

The distinction between the Eocene pollen flora of Massachusetts and the Oligocene pollen flora of Vermont may not be immediately obvious because only a moderate number of Eocene genera have actually been found in Massachusetts (Frederiksen, 1984a). However, if much larger lists of early to middle Eocene pollen taxa from Virginia and South Carolina are examined (Frederiksen, 1979, 1980, 1984b), a considerable difference can be seen between the Eocene flora of the Atlantic Coastal Plain and the Oligocene flora of Vermont, particularly with regard to zoophilous forms. Many wind-pollinated taxa listed by Traverse (1955; *see* Table 3 of this paper) from the Brandon deposit were also found in the Eocene, for example, Pinaceae and Taxodiaceae-Cupressaceae-Taxaceae; Engelhardieae, *Pterocarya, Juglans,* and *Carya* of the Juglandaceae; *Castanea* and *Quercus* types of the Fagaceae; *Ulmus* and *Planera* types of the Ulmaceae. Some taxa having zoophilous pollen are also represented in floras of the two time spans, for example, Alangiaceae (*Alangium*), Anacardiaceae (*Rhus*), Aquifoliaceae (*Ilex*), Cyrillaceae, Nyssaceae, Sapotaceae, Symplocaceae, and Tiliaceae (*Tilia* type). However, the early and middle Eocene pollen floras of the Atlantic Coastal Plain contain many angiosperm taxa that became extinct before the end of the Eocene; these extinct taxa are probably mainly zoophilous, and they give the Eocene floras a much warmer climatic appearance than the Oligocene flora from Brandon.

The known Eocene and Oligocene floras of New England were different partly because they were separated by at least 20 m.yr. in age (52–58 Ma. vs. perhaps 24–30 Ma.). Evolution, extinction, and climatic change had been active during this time span. As noted above, the Eocene flora of Massachusetts is early Eocene in age; the early Eocene was the warmest part of the entire Tertiary in North America (Wolfe and Poore, 1982; Wolfe and Upchurch, 1987). In contrast, the Brandon flora postdates the Oligocene climatic deterioration (of Wolfe, 1971 = the terminal Eocene event of Wolfe, 1978); this rapid cooling (and drying?) event probably commenced at the beginning of Oligocene time, at least on the Gulf Coast (Frederiksen, 1988). Thus, between early Eocene and late Oligocene time, the vegetation of New England had probably changed from tropical rainforest to deciduous broadleaved forest (Wolfe, 1985) or Mixed Mesophytic forest (Figure 2).

MIOCENE OF MASSACHUSETTS

The Miocene pollen flora of Massachusetts is quite well known because it has been found at six localities in Plymouth County and Martha's Vineyard (Frederiksen, 1984a). One of these outcrops has been dated as middle Miocene in age on the basis of vertebrate fossils. The exact ages of the remaining five localities have not been independently established, but they all have similar pollen assemblages. Because they all seem to represent vegetation of the mid-Miocene warming, which was restricted to the late early and early middle Miocene (Wolfe, 1985), they are probably all similar in age. The Miocene flora is rich in taxa of both gymnosperm and dicotyledonous trees and is relatively rich in taxa of low shrubs, herbs, and vines (Table 3).

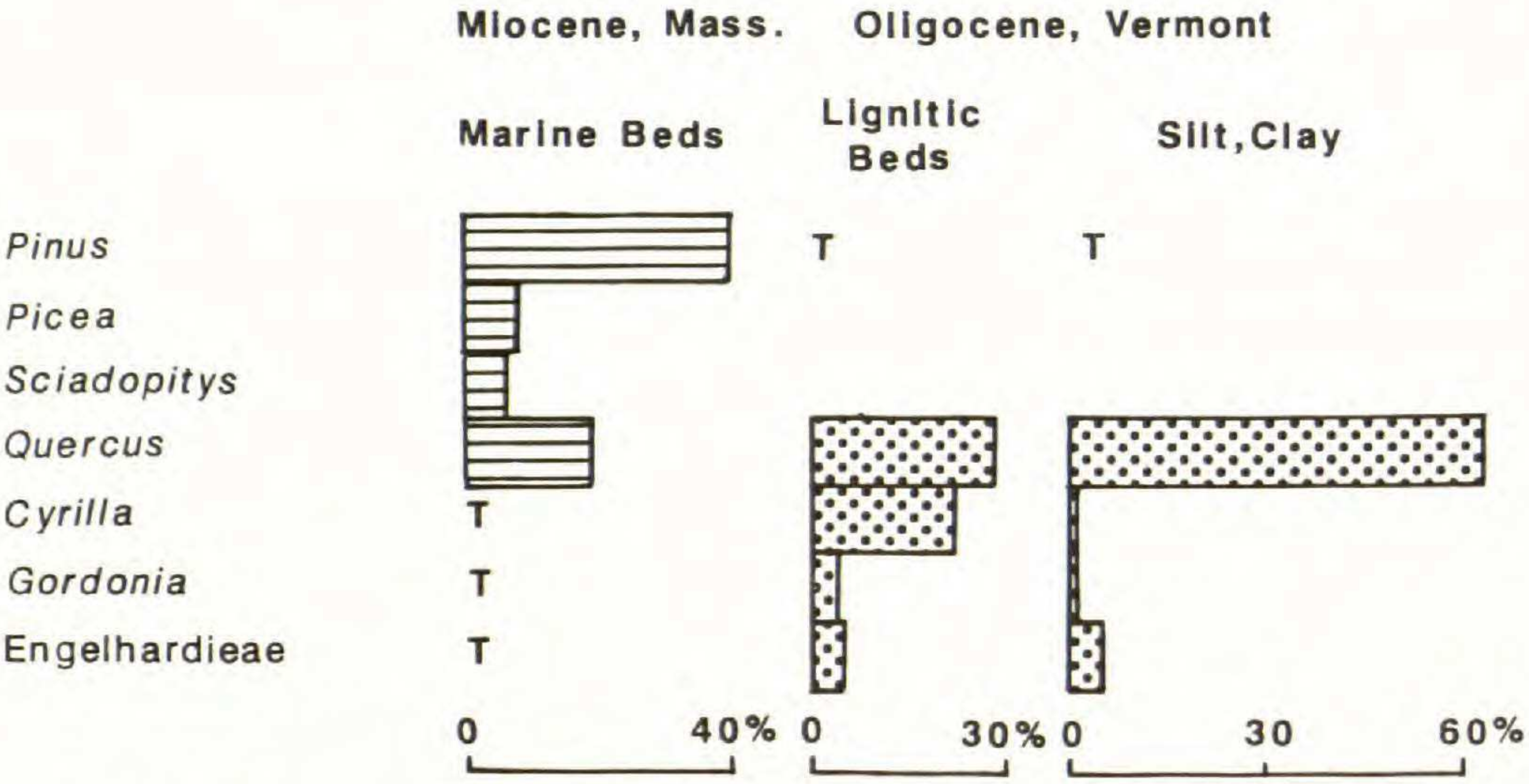

Figure 4. Relative frequencies of the more abundant pollen types in the Oligocene of Vermont (Traverse, 1955) and the Miocene of Massachusetts (Frederiksen, 1984a). T = trace = <1%.

COMPARISON OF OLIGOCENE AND MIOCENE FLORAS

Table 3 compares the Oligocene and Miocene pollen floras of New England. Both floras have about the same taxa of dicotyledonous trees. The apparent absence of *Alnus, Platanus,* and *Salix* from the Oligocene flora is surely due to ecological factors. *Alangium* is present in the Oligocene flora of Vermont but was not observed in the Miocene flora of Massachusetts; however, pollen of this genus has been found in middle Miocene samples from New Jersey (Wolfe and Tanai, 1980; Owens et al., in press). The presence of *Betula* in the Miocene but not in the Oligocene suggests a slightly cooler climate in Miocene time; similarly, *Planera,* a genus presently restricted to the Southeast in the United States, which was found in the Oligocene but not the Miocene, suggests a slightly warmer climate in Oligocene time.

The most obvious difference between the Oligocene and Miocene floras is in the higher diversity of conifers and low shrubs, herbs, and vines in the Miocene than in the Oligocene flora. On the Atlantic Coastal Plain, *Sciadopitys* is probably restricted to the Miocene (Frederiksen, 1984a). The paleoclimatic significance of this genus in the Tertiary is difficult to evaluate except that it was much more widely distributed in the Northern Hemisphere in Tertiary time than now and therefore must have had a broader climatic range (Frederiksen, 1985). The apparent lack of *Podo-*

carpus pollen in the Oligocene flora is surprising, as pollen of this genus is common in Cretaceous and lower Tertiary rocks of the eastern United States, and it is found in most Miocene samples from Massachusetts (Frederiksen, 1984a). *Pinus* pollen is sparsely represented in the Oligocene samples, even in assemblages from clay and silt that contain largely pollen from outside the peat swamp, whereas pine pollen is 36–45% of the entire pollen assemblage in Miocene samples from Massachusetts (Frederiksen, 1984a) (Figure 4). Pine trees produce enormous amounts of pollen; thus, pines must have lived at some distance from the Brandon depositional basin.

As regards low shrubs, herbs, and vines of the two floras, the most significant difference is the presence of Compositae and Umbelliferae pollen in the Miocene flora and the absence of pollen of these families in the Oligocene assemblage. Compositae pollen is rare if present at all in Oligocene deposits, and for most practical purposes it first appears at the beginning of the Miocene (Muller, 1981). Umbelliferae pollen has been found in Europe in rocks as old as Eocene (Muller, 1981), but it has not been recognized in North America in lower Tertiary strata. Thus, the apparent absence of Compositae and Umbelliferae fossils from the Brandon flora probably has age or possibly paleoecologic rather than paleoclimatic significance. Surely Chenopodiaceae-Amaranthaceae, *Myrica, Myriophyllum,* and *Sparganium-Typha* are lacking from the Brandon Oligocene pollen assemblages only for paleoecologic reasons. The marsh herb *Caldesia* (Alismataceae) has been identified in the Oligocene flora on the basis of fruits (Tiffney, 1985).

Differences exist between the Oligocene and Miocene floras of New England with regard to exotic elements, that is, modern genera that no longer live in the United States, but the differences are difficult to evaluate. Ten such genera or generic groups were found in the Brandon deposit (Table 2), but six of them (*Caldesia, Cleyera, Euodia, Microdiptera, Phellodendron, Turpinia*) were found only as megafossils, not as pollen, no doubt because they are zoophilous. In addition, the Brandon seed and fruit flora includes the extinct genera *Moroidea* (Moraceae) and *Caricoidea* (Cyperaceae) as well as Myrtaceae? (B. H. Tiffney, written comm., 1988). The exotic genera and generic groups *Alangium, Glyptostrobus,* Engelhardieae, and *Pterocarya* were found as pollen in the Brandon deposit; most or all of these probably existed in New England in Miocene time as well. In addition, the Miocene pollen assemblages include *Sciadopitys* and *Podocarpus*. In short, as far as can be determined from pollen, the Miocene flora of New England included at least as many exotic modern genera as the Oligocene flora.

It is not easy to compare the vegetation and climate of the Vermont Oligocene with the vegetation and climate of the Massachusetts Miocene, particularly because both sets of deposits lack fossil leaves that are critical for quantitative climatic analysis. In fact, only small Oligocene or late Tertiary leaf floras are available from anywhere in eastern North America (Wolfe, 1978). In the following paragraphs, I summarize conclusions about the Oligocene of Vermont, then about the Miocene of Massachusetts, and then compare the two.

The flora of the Brandon deposit shows that the late Oligocene climatic regime in the area was distinctly warmer than now (Table 2). Traverse (1955) considered the Oligocene flora of Vermont to be most similar to the extant flora of the southeastern United States. Tiffney (1977a) and Wolfe (1979) noted that the Brandon flora appeared to contain both evergreen and deciduous broadleaved elements; Tiffney regarded the climatic affinity as being subtropical to paratropical. Wolfe (1979, p. 26) stated that the Brandon flora may represent evergreen broadleaved forest, but later (1985) he considered the Brandon flora to represent deciduous broadleaved forest that lay to the north of evergreen broadleaved forest.

Considering the taxa present in the Miocene pollen flora (Table 3) and relative frequencies of the various pollen types (Figure 4), Frederiksen (1984a) concluded that the Miocene flora of Massachusetts represented high-diversity low-dominance Mixed Mesophytic forest somewhat similar to the modern forest of the central to southern Appalachian Mountains except that the Miocene forest had a larger component of conifers than the modern Appalachian forest. On the basis of sparse plant megafossils, Wolfe (1977, p. 48) also thought that the Miocene vegetation of the eastern United States was probably Mixed Mesophytic forest.

The main question regarding the late Oligocene and middle Miocene vegetation of New England is the role of conifers in the lowland forests of the two time spans. In his 1985 vegetation map, Wolfe (1985, Figure 11) combined data from the late Oligocene and early Miocene and showed New England as dominated by deciduous broadleaved forest with the northern Appalachian Mountains covered by mixed coniferous forest. In this view, apparently, most conifers were in the uplands, and this would explain why conifer pollen and megafossils are so scarce in the Oligocene Brandon lowland deposit in which the plant fossils (at least in the lignite) represent the local flora. In contrast, conifer pollen is abundant in assemblages from Miocene marine strata of Massachusetts, which represent the regional flora (Figure 4). Does this Miocene pollen reflect abundance of conifer trees in the lowland vegetation of the time (the interpretation of Frederiksen, 1984a), or did the conifer pollen come mainly from the uplands (apparently the interpretation of Wolfe, 1985)? Probably both interpretations are correct to some extent. For example, *Picea* and *Tsuga* are unlikely to have grown in close proximity to *Cyrilla-Cliftonia, Gordonia,* Sapotaceae, and *Symplocos* in the lowland Miocene forests. On the other hand, *Pinus, Sciadopitys,* and possibly *Podocarpus* may have lived in the warm lowlands. It seems unlikely that a 40% relative abundance of pine pollen in the Miocene marine sediments could be due entirely to long-distance transport from the mountains. Additionally, *Sciadopitys* trees were very abundant in some Miocene lowland peat swamps of northwestern Europe (Thiergart, 1949).

In summary, differences between the Oligocene and Miocene pollen floras are obvious but somewhat difficult to interpret especially with respect to vegetation types and paleoclimates. Differences in dicotyledonous tree taxa of the two time spans are minimal (Table 3). The presence in the Miocene pollen assemblages of *Abies*(?), *Larix*(?), *Picea, Tsuga,* and *Betula* and the much higher relative frequencies of conifer pollen in the Miocene assemblages are undoubtedly partly an effect of regional as opposed to local pollen catchment, but conifers appear to have been more abundant (and the climate perhaps a little cooler) in New England in middle Miocene than in late Oligocene time. However, the lowland vegetation of both time spans could probably be termed Mixed Mesophytic forest. Other differences between the Oligocene and Miocene floras are results of evolution (Compositae and Umbelliferae in Miocene assemblages) and immigration followed by regional extinction (*Sciadopitys* in Miocene assemblages).

PLIOCENE OF MASSACHUSETTS

Two pollen samples of Pliocene (or possibly latest Miocene) age are known from Martha's Vineyard (Frederiksen, 1984a). These samples contain very low-diversity assemblages that con-

Table 4. Taxa recorded from Pliocene pollen and spore assemblages of Massachusetts (Frederiksen, 1984a).

TREES
- **Gymnosperms**
  - *Picea*
  - *Pinus*
- **Dicotyledons**
  - *Alnus*
  - *Betula*

LOW SHRUBS, HERBS, VINES
- Caryophyllaceae?
- Compositae, short-spined
- Ericaceae
- Gramineae
- *Myrica*?

PTERIDOPHYTES AND BRYOPHYTES
- *Botrychium*?
- *Lycopodium*
- *Selaginella*
- *Sphagnum*

sist mostly of pollen of *Pinus,* shrubs and herbs, and spores of *Sphagnum* and pteridophytes (Table 4). The climate in which the flora lived was probably cool temperate. This flora is far less diverse than that of the Miocene, and no exotics have been found among the Pliocene spore and pollen taxa.

CONCLUSIONS

The Late Cretaceous and Tertiary plant fossil record of New England consists of megafossils from the Late Cretaceous and Oligocene epochs and pollen from the Late Cretaceous and from each epoch of the Tertiary (Figure 2). The fossils represent only bits and pieces of the time span between 93 and 1.5 Ma. However, the data points in New England, and data from elsewhere in North America, are sufficient to demonstrate distinct changes in floras and vegetation types corresponding to a change of climate that was paratropical in the Cretaceous, reached a maximum warmth in the early Eocene, and then cooled into the Pliocene and of course became even colder in the Quaternary.

This paper shows that, to obtain a Late Cretaceous and Tertiary floral, vegetational, and climatic history of New England, megafossil evidence is critical for reconstructing vegetation and climate, but only a few time spans are represented by megafossils in this region; most of the plant megafossil data come from rather far away. On the other hand, the pollen assemblages contribute much of the total floral data, because they represent many more geologic time data points in New England itself than do the megafossils.

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